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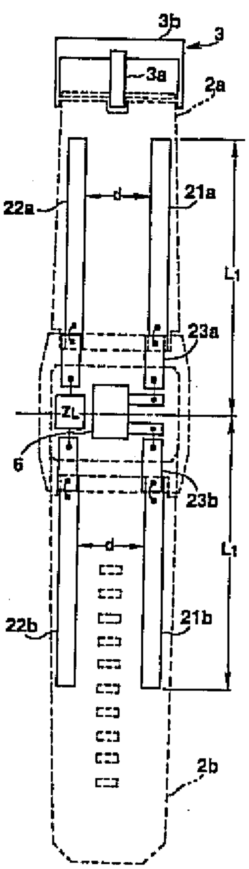
(54) Antenna for use with a portable radio apparatus

(57) An antenna for use in a portable radio apparatus, which has a pair of bands (2a, 2b) extending from the main body (1) of the apparatus, for securing the apparatus to a user. A first antenna conductor (21a or 21b) supplied with power and a second antenna conductor (22a or 22b) not supplied with power are embedded in each of the bands (2a, 2b) and extend parallel to the axis of the band (2a or 2b). The first and second antenna conductors (21a, 22a) embedded in the first band (2a) are connected at one end to the first and second antenna conductors (21b, 22b) embedded in the second band (2b). No load is connected to the second antenna conductor (22a or 22b) embedded in each band (2a or 2b). The second antenna conductor (22a or 22b) embedded in each band (2a or 2b) performs different functions according to its length. If it has a length equal to or greater than half the wavelength λ of waves to receive, it will function as a reflector. If it has a length less than half the wavelength λ of the waves, it will function as a director. The four antenna conductors (21a, 21b, 22a, 22b) are adjusted in length and position, constituting an antenna which has high sensitivity and which is small enough to be incorporated into a portable radio apparatus.

FIG.6A



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Description

The present invention relates to an antenna for use in a portable radio apparatus and, more particularly, to an antenna which is to be incorporated in the housing of a radio apparatus or in a peripheral device to the radio apparatus.

Portable radio apparatuses of various types, such as portable radio receivers and pagers, are commercially available. They are used in great numbers because they are small, light and useful. They have an antenna to receive radio waves. In most cases, the antenna is provided in the housing of the apparatus or in a peripheral device to the apparatus.

The recent advancement in the integrated circuit technology has provided miniaturized components of radio-circuit components which consume but a little power. Additionally, small, high-performance and large-capacity dry cells and rechargeable batteries for use in portable radio apparatuses have come into practical use. However, antennas for use in portable radio apparatuses have yet to be miniaturized. This is because the power an antenna can output is proportional to the wave-receiving area of the antenna and the length of the antenna. It should be noted that the antenna length is closely related to the lengths of radio waves to detect.

Among portable radio apparatuses hitherto developed is a watch-shaped one which comprises a case and a band. If it is an AM radio, it has a bar antenna provided within the case, for receiving MF (Middle-Frequency) radio waves. If it is an FM radio or a pager, it has a loop-type band antenna incorporated in the band, for receiving FM (Frequency-Modulated) radio waves. A portable FM radio receiver and a pager, i.e., two other types of portable radio apparatus, have a cord-type antenna which functions as an earphone, as well.

Conventional antennas, such as a bar antenna, a cord-type antenna and a loop-type band antenna, for use in portable radio apparatuses, are disadvantageous in the following respects.

(a) The bar antenna or the like to be set within the case of a watch-shaped radio apparatus cannot perform a desired function if used in combination with a pager, a mobile telephone or a personal digital assistance (PDA) having a radio receiver/transmitter, which needs to receive high-frequency radio waves of hundreds of megahertzes to several gigahertzes. Further, in order to accommodate the bar antenna or the like, the case must be made of electrically conductive material such as metal.

(b) The cord-type antenna for use in a portable FM radio receiver, which functions also as an earphone, has to be connected to or wrapped around the receiver when it is used.

(c) The loop-type band antenna has a complex structure, and the manufacturing cost of its antenna section is high. This is because a loop must be formed when the antenna is connected to the buckle of the wrist band. Since the antenna is wrapped around the wrist, the diameter of the loop changes with the size of the wrist, inevitably changing the antenna length. To maintain the characteristics of the antenna, an adjusting circuit must be used to compensate for the change in the antenna length.

(d) Even if a metal conductor is bonded to the band of the watch-shaped radio apparatus, the characteristics of the antenna remain unstable. This is because the size of the antenna is limited and also because the conductor or the wrist, which is also a conductor, extends through the antenna loop. As a consequence, the antenna cannot have a sensitivity as high as desired and cannot receive or transmit radio waves reliably.

(e) Generally, the ratio of the radiation resistance to the input resistance is small in the loop antenna. Further, the loop antenna cannot be used unless the input reactance is canceled out. It has be used at an extremely low efficiency.

Accordingly it is the object of the present invention to provide an antenna for use in a portable radio apparatus, which can be used as a radio apparatus using high-frequency waves of ultrashort-wave band or a higher band, which can be manufactured at low cost and which has good characteristics to increase the sensitivity, efficiency and stability of the radio apparatus. To achieve the object, there is provided an antenna for use in a portable radio apparatus, comprising: band sections extending from a main body of the apparatus for securing the apparatus to a user; a first conductor provided at each of the band sections and made of plastic material, supplied with power at a center part such that a current distribution is symmetrical with respect to the center part; and a second conductor provided at each of the band sections, made of plastic material and spaced apart from the first conductor by a predetermined distance.

Having this specific structure, the antenna can be very portable, can reliably receive radio waves of various frequencies and can yet be manufactured at low cost.

This invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

FIGS. 1A and 1B are a front view and sectional view of a watch-shaped radio apparatus equipped with an antenna according to a first embodiment of the present invention;

FIGS. 2A and 2B are, respectively, a diagram showing the antenna and an equivalent circuit diagram thereof, respectively;

FIGS. 3A and 3B are a diagram showing the antenna according to a second embodiment of the invention and an equivalent circuit diagram thereof, respectively;

FIGS. 4A and 4B are a diagram illustrating a modification of the antenna shown in FIG. 3A and an equivalent circuit diagram of the modified antenna, respectively;

FIGS. 5A, 5B and 5C are a diagram showing an antenna according to a third embodiment of the invention, an equivalent circuit diagram thereof and a schematic diagram thereof, respectively.

FIGS. 6A and 6B are a diagram representing the antenna according to a fourth embodiment of this invention and an equivalent circuit diagram thereof, respectively;

FIGS. 7A and 7B are a diagram illustrating a modification of the antenna shown in FIG. 6A and an equivalent circuit diagram of the modified antenna, respectively;

FIGS. 8A and 8B are a diagram showing another modification of the antenna shown in FIG. 6A and an equivalent circuit diagram of this modified antenna, respectively;

FIGS. 9A and 9B are a diagram illustrating still another modification of the antenna shown in FIG. 6A and an equivalent circuit diagram of this modified antenna, respectively;

FIGS. 10A and 10B are a diagram showing a further modification of the antenna shown in FIG. 6A and an equivalent circuit diagram of the modified antenna, respectively;

FIGS. 11A and 11B are a front view of a watch-shaped radio apparatus equipped with an antenna which is a fifth embodiment of the invention, and a schematic view of the antenna, respectively;

FIGS. 12A and 12B are a schematic view of the antenna shown in FIG. 11B and a schematic view of a folded antenna, respectively;

FIGS. 13A through 13E are equivalent circuit diagrams of the antenna according to the fifth embodiment;

FIG. 14 is an equivalent circuit diagram of the antenna according to the fifth embodiment of the invention;

FIG. 15 is a schematic representation of an antenna according to a sixth embodiment of the present invention;

FIGS. 16A and 16B are a schematic diagram of equivalent circuit diagram of the antenna shown in FIG. 15, respectively;

FIG. 17 consists of a front view and sectional view of a watch-shaped radio apparatus equipped with a patch antenna which is a seventh embodiment of the present invention;

FIG. 18 consists of a front view and a sectional view of the patch antenna according to the seventh embodiment;

FIG. 19 is a perspective view of a micro-strip line, explaining the operating principle of the patch antenna;

FIGS. 20A, 20B and 20C are an equivalent circuit diagram of a micro-strip antenna, a graph showing the current- and voltage-distribution in the micro-strip antenna and a sectional view of the micro-strip antenna, respectively;

FIGS. 21A and 21B are, respectively, a perspective view of a micro-strip line made in the form of a rectangular patch and a diagram illustrating how power is radiated from the micro-strip line;

FIGS. 22A and 22B show an electric field generated at a conductor plate having a slot in the center part and an electric field generated from a small dipole current;

FIGS. 23A and 23B are, respectively, a diagram showing a magnetic current flowing in a patch antenna and a diagram illustrating a rectangular loop antenna in which a current flows in the same way as the magnetic current;

FIGS. 24A, 24B 24C and 24D are a perspective view of a patch antenna, a perspective view of a small patch antenna, a diagram showing an inverted-L antenna and a diagram showing an inverted-F antenna, respectively;

FIG. 25 consists of a front view of a patch antenna, a sectional view of the patch antenna and a diagram showing the current-voltage characteristic thereof, respectively;

FIG. 26 consists of a front view of another patch antenna, a sectional view of the patch antenna and a diagram showing the current-voltage characteristic thereof, respectively;

FIG. 27 consists of a front view of still another patch antenna, a sectional view of this patch antenna and a diagram showing the current-voltage characteristic thereof, respectively;

FIG. 28 is a schematic representation of an antenna according to an eighth embodiment of the present invention;

FIG. 29 is a sectional view of a part of the antenna shown in FIG. 28;

FIGS. 30A through 30C are front views of the antenna of FIG. 28, illustrating the layers which constitute the antenna;

FIGS. 31A and 31B are a front view and partially sectional view of an antenna according to a ninth embodiment of the invention;

FIGS. 31C and 31D are front views of the antenna shown in FIGS. 31A and 31B, illustrating the layers which constitute the antenna;

FIGS. 32A and 32B are a front view and partially sectional view of an antenna according to a tenth embodiment of the invention;

FIGS. 32C and 32D are front views of the antenna shown in FIGS. 32A and 32B, illustrating the layers which constitute the antenna;

FIGS. 33A and 33B are a front view and partially sectional view of an antenna according to an eleventh embodiment of the invention;

FIGS. 33C and 33D are front views of the antenna shown in FIGS. 33A and 33B, illustrating the layers which constitute the antenna;

FIG. 34 is a block diagram of a watch-shaped, FM stereophonic radio/FM teletext receiver whose receiving antenna is a patch antenna according to the invention;

FIG. 35 is a block diagram of a watch-shaped, FM wireless microphone/FM character code transmitter whose transmitting antenna is a patch antenna according to this invention; and

FIG. 36 is a block diagram of a watch-shaped mobile telephone whose receiving/transmitting antenna is a patch antenna according to the invention.

Embodiments of the present invention will be described, with reference to the accompanying drawings. The embodiments are designed for use in watch-shaped portable radio apparatuses.

First Embodiment

1. Structure

FIG. 1A is a front view of a watch-shaped radio apparatus equipped with a band antenna which is the first embodiment of the present invention. FIG. 1B is a sectional view of the watch-shaped radio apparatus. As shown in FIG. 1A, the radio apparatus comprises a main body 1, two band sections 2a and 2b, and a buckle section 3. The main body 1 contains electronic components which perform watch function and radio-apparatus function. The band sections 2a and 2b are connected to the main body 1 to secure the main body 1 to a user's wrist. The buckle section 3 fastened to the free end of the band section 2a. The main body 1 has a display 1b which is an LCD or the like, on its upper surface. On its each side the main body 1 has two switches 1c.

A ring 4 is mounted on the band section 2a. Into this ring 4 the user inserts the other band section 2b when he or she wraps both band section 2a and 2b around the wrist to wear the watch-shaped radio apparatus. The band section 2b has a row of holes 5. The buckle section 3 has a pin 3a and a decorative ring 3b. The user inserts the pin 3a into one of the holes 5 to secure the radio apparatus on his or her wrist. The pin 3a remains in contact with the decorative ring 3b as long as the user wears the watch-shaped radio apparatus.

The main body 1 contains a radio circuit section 6 and conductive power-supply terminals 7a and 7b. The radio circuit section 6 is designed to supply power to antenna conductors 10a and 10b, which will be described later. An input/output terminal projects from the section 6, for supplying to the section 6 the power the antenna conductors 10a and 10b have received. The input/output terminal is connected to conducive bases 11a and 11b, both electrically and physically. The power-supply terminals 7a and 7b extend in the axial direction of the band section 2a and 2b. They are connected at one end to the base 11a and 11b, respectively, both electrically and physically by, for example, solder.

In the band section 2a, the other end of the power supply terminal 7a is electrically and physically secured by a conductive screw 7c to one end of the antenna conductor 10a which extends in the axial direction of the band section 2a. In the band section 2b, the other end of the power supply terminal 7b is electrically and physically secured by a conductive screw 7d to one end of the antenna conductor 10b which extends in the axial direction of the band section 2b. The antenna conductors 10a and 10b are metal strips, thin metal strips or wires, which are plastic members. The power-supply terminal 7a is provided between the main body 1 and the band section 2a, and the power-supply terminal 7b between the main body 1 and the band section 2b. Both power-supply terminals 7a and 7b are made of flexible material, allowing the sections 2a and 2b to move with respect to the main body 1.

2. Electrical Characteristics

FIG. 2A is a schematic representation of the above-mentioned band antenna, and FIG. 2B is an equivalent circuit diagram of the band antenna. As shown in FIG. 2A, the band antenna has an antenna length L1 which is the sum of the length of the power-supply terminal 7a and that of the antenna conductor 10a. The antenna length L1 is given as:

$$2L_1 = \frac{\lambda}{2} \qquad (1)$$

$$\therefore L_1 = \frac{\lambda}{4} \ (\lambda\text{: wavelength})$$

The band antenna is therefore identical in structure to a so-called "half-wave dipole antenna, which will be hereinafter referred to as "half-wave antenna." Most half-wave antennas are omnidirectional in two planes which are symmetrical with respect to the antenna axis and which are located at the same distance from the antenna axis. The input impedance of a half-wave antenna is expressed as follows:

$$Z_{2L} = (\frac{\lambda}{2} + \Delta) \cong 73.13 + j42.55 + jWek\Delta \quad (\Omega)$$
$$\cong 73.13 + j42.55 + \underset{\downarrow}{\underline{j60 \cdot \ln(2L / \rho)}} \quad (\Omega)$$
$$\begin{pmatrix} \text{or } j60 \cdot \log_e(2L / \rho) \\ \cong j138 \cdot \log_{10}(2L / \rho) \end{pmatrix} \qquad (2)$$

where 2L (= 2L1) is the total antenna length, ρ is the diameter of either antenna conductor, $k = 2\pi/\lambda$, λ is the wavelength, and We is the wave impedance. The resistance R of the half-wave antenna is substantially proportional to the square of the total length 2L (= $\lambda/2$). That is, the less the total length 2L, the lower the resistance R. Hence, the input reactance X of the antenna changes almost linearly with the total length 2L. The greater the diameter ρ of the antenna conductors, the greater the input reactance X, provided that the total length 2L is relatively small.
Generally, it is desirable that the input impedance of the half-wave antenna be almost the same as forward resistance. To make the input impedance as nearly equal to the forward resistance, it is required, as can be understood from the equation (2), that the total length 2L be a little less than half-wave length E$\lambda/2$. In other words, it suffices to set the half antenna-length L (= L1) at 0.90 to 0.95 times $\lambda/4$.

The radiation power Wr of the half-wave antenna is defined as follows:

$$\begin{aligned} Wr &\cong 60|I|^2 \int_0^{\pi} \frac{\cos^2(\frac{\pi}{2}\cos\theta)}{\sin\theta} d\theta \\ &= 30|I|^2(\gamma + \ln 2\pi - Ci2\pi) \\ &= 30|I|^2 \times 2.44 \ldots \\ &\cong 73.13|I|^2 (W) \end{aligned} \qquad (3)$$

$$\begin{pmatrix} \gamma : \text{Eiler's constant, Ci:cosine integtal,} \\ \gamma = 0.577\ldots\ldots \\ Ci(z) = -\int_z^{\infty} \frac{\cos x}{x} dx \end{pmatrix}$$

The radiation resistance Rr of the antenna is represented by the following equation:

$$Rr = \frac{Wr}{|I|^2} = 73.13\ (\Omega) \qquad (4)$$

The directional gain Gd of the antenna is given as:

$$\begin{aligned} Gd &= \frac{1}{\int_0^{\frac{\pi}{2}} \frac{\cos^2(\frac{\pi}{2}\cos\theta)}{\sin\theta} d\theta} \\ &= \frac{4}{2.44\ldots} = 1.6409\ldots \end{aligned} \qquad (5)$$

Obviously, the gain Gh is 4 to 5dB greater than the gain Gd of the half-wave antenna of the first embodiment, when the distance d ranges from 2.5 to 3 times $\lambda/4$.

Modification of the Second Embodiment

FIG. 4A is a diagram illustrating a modification of the second embodiment shown in FIG. 3A, and FIG. 4B is an equivalent circuit diagram of the modified band antenna. The modified band antenna has two U-shaped antenna conductors 15a and 15b which are embedded in band sections 2a and 2b, respectively. The antenna conductors 15a and 15b extend in the axial direction of the sections 2a and 2b. They are electrically connected to power-supply terminals 16a and 16b. Each antenna conductor has two parallel portions which have different lengths L1 and L2 (L1 < L2) and which are spaced apart by a distance d. The modified band has characteristics similar to those of the second embodiment shown in FIGS. 3A and 3B.

Third Embodiment

FIG. 5A is a diagram showing a band antenna which is the third embodiment of the invention. FIG. 5B is an equivalent circuit diagram of this band antenna. FIG. 5C is a schematic representation of the band antenna.

As illustrated in FIG. 5A, two antenna conductors 17a and 18a are embedded in a band section 2a, are spaced apart by a distance d and extend in the axial direction of the band section 2a. Similarly, two antenna conductors 17b and 18b are embedded in a band section 2b, are spaced apart by distance d and extend in the axial direction of the band section 2b. The antenna conductors 17a and 18a are electrically connected to a radio circuit section 6 (i.e., power-supply section) by power-supply terminals 20a and 20b. The antenna conductors 17b and 18b are electrically connected to a radio circuit section 6, too, by power-supply terminals 20c and 20d. A phase shifter 21 is provided on the line connecting the power-supply terminal 20b to the radio circuit section 6. Due to the phase shifter 21, the conductors 17a and 18a function as a half-wave antenna which differs in phase from the half-wave antenna constituted by the conductors 17b and 18b. Thus, even if the distance d is reduced, the band antenna can acquire characteristics as good as those of an antenna in which the distance d ranges $5\lambda/8$ to $3\lambda/4$ and which therefore has a great gain. The third embodiment therefore equals the first and second embodiments in antenna characteristics.

Fourth Embodiment

FIG. 6A is a diagram representing the band antenna which is the fourth embodiment of the invention, and FIG. 6B is an equivalent circuit diagram of the band antenna. As seen from FIG. 6A, antenna conductors 21a and 22a are embedded in a band section 2a and extend in the axial direction of the section 2a. Also, antenna conductors 21b and 22b are embedded in a band section 2b and extend in the axial direction of the section 2b. Of the four antenna conductors, only the conductors 21a and 21b are electrically connected to a radio circuit section 6 (i.e., power-supply section) by power-supply terminals 23a and 23b, respectively. The other conductors 22a and 22b are connected in series to each other by a load ZL. The conductor 22a is spaced from the conductor 21a by a distance d, and the conductor 22b from the conductor 21a by the same distance d. An intense electric field is generated in the vicinity of the conductors 21a and 21b when power is supplied to these conductors 21a and 21b. As a result, a current flows through the conductors 22a and 22b located near the conductors 21a and 21b, though power is supplied to neither the conductor 22a nor the conductor 22b. The conductors 22a and 22b therefore function as antenna conductors. To be more precise, they operate as reflectors or directors.

The input impedance the entire antenna has, i.e., the input impedance at the antenna conductors 21a and 21b, is expressed by the following equation:

$$Z = Z_{11} - \frac{{Z_{12}}^2}{Z_{22} + Z_L} \qquad (9)$$

The gain Gh (θ, ϕ) of the half-wave antenna comprised of antenna conductors 21a and 21b is defined by the following equation:

$$Gh(\theta,\phi) = \frac{R_0}{R}\left|1 - \frac{Z_{22}e^{jkd \sin\theta \cos\phi}}{Z_{22}}\right|^2 \frac{\cos^2(\frac{\pi}{2}\cos\theta)}{\sin^2\theta} \qquad (10)$$

where R_0 is the radiation resistance of the half-wave antenna, given as follows.

$$R_0 = \frac{Wr}{|I|^2} \approx 73.13\ (\Omega)$$

As can be understood from the equation (10), the input impedance and gain of the half-wave antenna can be changed by adjusting the load ZL connected between the antenna conductors 22a and 22b to which no power is supplied. If the load ZL is adjusted, thus increasing the gain in the direction where $\phi = 0$, the antenna conductors 22a and 22b will work as directs. If the load ZL is adjusted, thereby increasing the gain in the direction where $\phi = 80$, the antenna conductors 22a and 22b will work as reflectors.

First Modification of the Fourth Embodiment

FIG. 7A is a diagram illustrating a first modification of the fourth embodiment, i.e., the band antenna shown in FIG. 6A. FIG. 7B is an equivalent circuit diagram of the first modified band antenna. As shown in FIG. 7A, no load ZL is used in this antenna, short-circuiting antenna conductors 22a and 22b to which no power is supplied. The conductors 22a and 22b therefore perform the same function of the reflectors of an antenna known as "Yagi-Uda antenna." In this modified antenna, the antenna conductors 22a and 22b differ in length from the antenna conductors 21a and 21b, thereby achieving the same results as can be attained by adjusting the value for the load ZL in the antenna shown in FIGS. 6A and 6B. To be more specific, if the length L2 of the antenna conductors 22a and 22b are longer or shorter than the antenna conductors 21a and 21b which constitute a half-wave antenna ($2L1 = \lambda/2$, $L1 = \lambda/4$), the reactance component of the self-impedance of each of the conductors 22a and 22b, the total length of which nearly equals the half-wave length $\lambda/2$, changes greatly, while the resistance component of the self-impedance changes a little. Hence, the change in the length L2 of the conductors 22a and 22b results in a change in the reactance X22 only.

If their length L2 is equal to or greater than $\lambda/4$ ($2L2 = \lambda/2$), the antenna conductors 22a and 22b will operate as reflectors, and the axial gain of the band antenna will decrease about 6dB. On the other hand, if their length L2 is 0.8 to 0.9 times $\lambda/4$, they will operate as directors, and the axial gain will increase 2db to 3dB. The thicker the antenna conductors 22a and 22b, the shorter they can be to work as directors.

Second Modification of the Fourth Embodiment

FIG. 8A is a diagram illustrating a second modification of the fourth embodiment, i.e., the band antenna shown in FIGS. 6A and 6B. FIG. 8B is an equivalent circuit diagram of the first modified band antenna. As shown in FIGS. 8A and 8B, antenna conductors 24a and 24b which are shorter than antenna conductors 21a and 21b are used, replacing the antenna conductors 22a and 22b which are longer than the conductors 21a and 21b. More precisely, the conductors 24a and 24b have a length L3 which is 0.8 to 0.9 times the length L1 of the conductors 21a and 21b. The conductors 24a and 24b, to which no power is supplied, are spaced apart from the conductors 21a and 21b, respectively, by a distance d3. The antenna conductors 24a and 24b operate as directors.

Third Modification of the Fourth Embodiment

FIG. 9A is a diagram illustrating a third modification of the fourth embodiment, i.e., the band antenna shown in FIGS. 6A and 5B. FIG. 9B is an equivalent circuit diagram of this modified antenna. As seen from in FIG. 8A, band sections 2c and 2d are provided which are broader than the band sections 2a and 2b shown in FIG. 6A. The band section 2d has two rows of holes. Three antenna conductors 25a, 26a and 27a are embedded in the band section 2c and spaced apart by a distance d3. Similarly, three antenna conductors 25b, 26b and 27b are embedded in the band section 2d and spaced apart by a distance d3. The conductors 25a and 25b are connected to a radio circuit section 6 (i.e., power-supply section), constituting a half-wave antenna. No power is supplied to the remaining conductors 26a, 26b, 27a and 27b, which operate as directors. To reverse the transmitting (or receiving) directivity of the band antenna while the conductors 26a, 26b, 27a and 27b are operating as directors, it suffices to exchange the positions of the conductors 25a and 25b and the radio circuit section 6 with the positions of the antenna conductors 26a and 26b.

Fourth Modification of Fourth Embodiment

FIG. 10A is a diagram illustrating a fourth modification of the fourth embodiment, i.e., the band antenna shown in FIGS. 6A and 6B. FIG. 10B is an equivalent circuit diagram of the fourth modified antenna. As illustrated in FIG. 10A, three antenna conductors 30a, 31a and 32a are embedded in a band section 2a, and three antenna conductors 30b, 31b and 31b in a band section 2b. The conductors 31a and 31b, which have a length L1, are connected to a radio circuit section 6 (i.e., power-supply section), constituting a half-wave antennas. The conductors 30a and 30b are located near

the conductors 31a and 31b, respectively, spaced apart therefrom by a distance d2. The conductors 32a and 32b are located near the conductors 31a and 31b, respectively, spaced apart therefrom by a distance d3.

The antenna conductors 30a and 30b have an effective length L2 which is greater than the effective length L1 of that of antenna conductors 31a and 31b. By contrast, the conductors 32a and 32b have an effective length L3 which is less than the effective length L1 of that of antenna conductors 31a and 31b. The conductors 20a and 30b constitute a reflector, whereas the conductors 32a and 32b constitute a director. The fourth modification is a three-component Yagi-Uda antenna provided in the form of a band antenna. The input impedance and gain of this antenna can be changed by adjusting the distance d3 between the conductors 31a and 31b, on the one hand, and the conductors 32a and 32b, on the other, and by adjusting the effective length L3 of the conductors 32a and 32b. The fourth modification is a three-component (reflector + reflector + antenna) antenna and has a gain which is 4 to 6dB greater than that of an ordinary half-wave antenna.

Fifth Embodiment

1. Structure

FIG. 11A is a front view of a watch-shaped radio apparatus equipped with an antenna which is the fifth embodiment of the present invention. FIG. 11B is a schematic view of the antenna. Like any embodiment described above, the fifth embodiment has a radio circuit section 6 and power-supply terminals 7a and 7b as is shown in FIGS. 11A and 11B. An input/output terminal projects from the radio circuit section 6. The input/output terminal is connected to conductive bases 11a and 11b, both electrically and physically by, for example, solder. The terminal is provided to supply power from the section 6 to antenna conductors 40a and 40b which are embedded in the band sections 2a and 2b, respectively, and to supply to the section 6 the power which the antenna conductors 40a and 40b have received. Further, power-supply terminals 7a and 7b extend in the axial direction of the band section 2a and 2b and are connected at one end to the base 11a and 11b, respectively, both electrically and physically by, for example, solder.

In the band section 2a, the other end of the power supply terminal 7a is electrically and physically secured to one end of the antenna conductor 40a which extends in the axial direction of the band section 2a. In the band section 2b, the other end of the power supply terminal 7b is electrically and physically secured to one end of the antenna conductor 40b which extends in the axial direction of the band section 2b. The antenna conductors 40a and 40b are metal strips, thin metal strips or wires, which are plastic members. The power-supply terminal 7a is provided between the main body 1 and the band section 2a, and the power-supply terminal 7b between the main body 1 and the band section 2b. Both power-supply terminals 7a and 7b are made of flexible material, allowing the sections 2a and 2b to move with respect to the main body 1.

The antenna conductor 40a consists of two power-supply antenna elements 42a and 43a which constitute a half-wave antenna having a total length (2L4) equal to half-wave length ($\lambda/2$). Similarly, the antenna conductor 40b consists of two power-supply antenna elements 42b and 43b which are parallel to each other, which are connected at one end to each other and which constitute a half-wave antenna having a total length (2L4) equal to half-wave length ($\lambda/2$).

2. Electrical Characteristics

As can be seen from FIG. 11B, the diameter $2\rho 2$ (radius = $\rho 2$) of the antenna conductors, to which no power is supplied, is one to six times as great as the diameter $2\rho 1$ (radius = $\rho 1$) of the antenna conductors 42a and 42b which constitute a half-wave antenna and to which power is supplied. The antenna conductors 42a and 43a are arranged, with their axes spaced apart by a distance d. Also, the antenna conductors 42b and 43b are arranged, with their axes spaced apart by a distance d.

Being large in size, the band antenna according to the fifth embodiment is used as a folded antenna in a high-frequency region. As shown in FIGS. 12A and 12B, a folded antenna is characterized in that the two conductors have radii $\rho 1$ and $\rho 2$ and the distance d between their axes are sufficiently small. When the folded antenna is used in place of a rod-shaped antenna such as a half-wave antenna of ordinary type, its input impedance can easily be changed to an appropriate value, without altering its radiation characteristic. Why so will be explained below.

Assume that a voltage V is applied and a current flows, at the power-supplying point of the folded half-wave antenna, as is illustrated in FIG. 13A. The electromagnetic field generated in this case is a combination of two electromagnetic fields shown in FIGS. 13B and 13C. The electromagnetic field of FIG. 13B is one generated when the same voltage Vr is applied at the axes of the two conductors, whereby currents Ir and arIr flow into the two conductors. The electromagnetic field of FIG. 13C is one generated when voltages afVf and -Vf are applied to the two conductors, respectively, whereby currents If and -If flow along the axes of the two conductors in the opposite directions.

Applying the reciprocity theorem to the two electromagnetic fields shown in FIGS. 13B and 13C, we obtain:

$$(V_r I_f - a_f V_f I_r) + \{V_r(-I_f) - (-V_f) a_r I_r\} = 0 \qquad (11)$$

FIG.6A

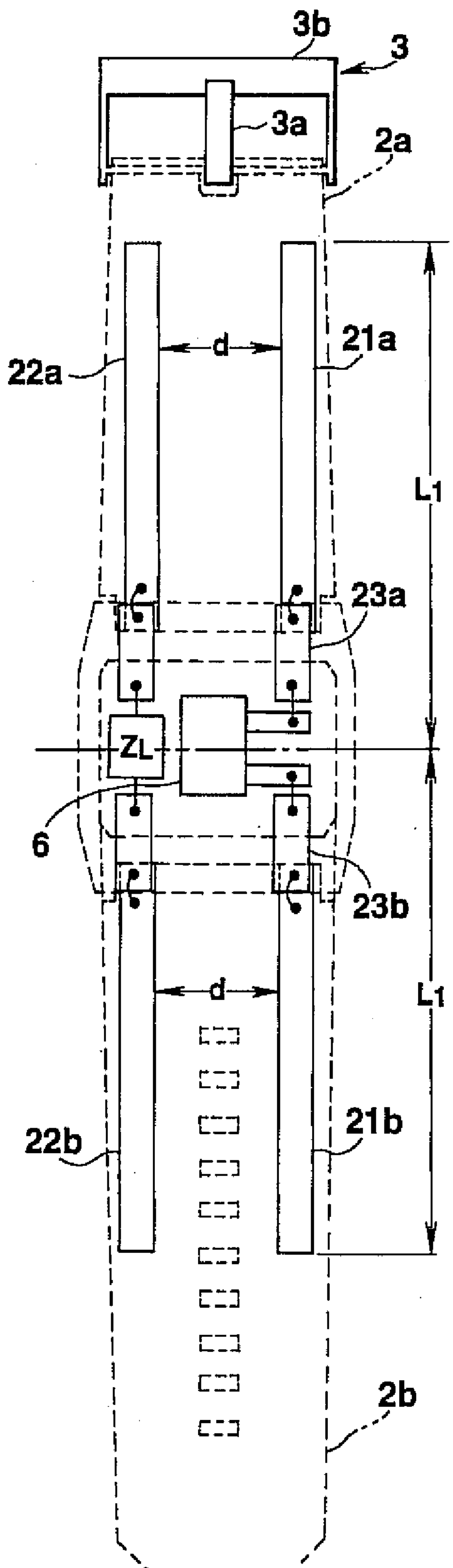
3b
3
3a
2a
22a
d
21a
L1
23a
ZL
6
23b
d
L1
22b
21b
2b

FIG.6B

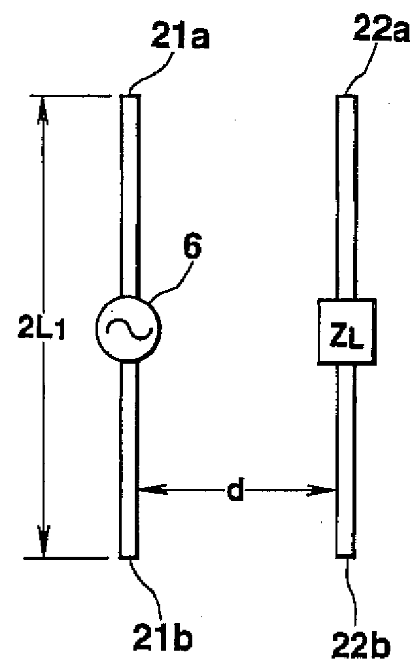
21a
22a
6
2L1
ZL
d
21b
22b

FIG.7A

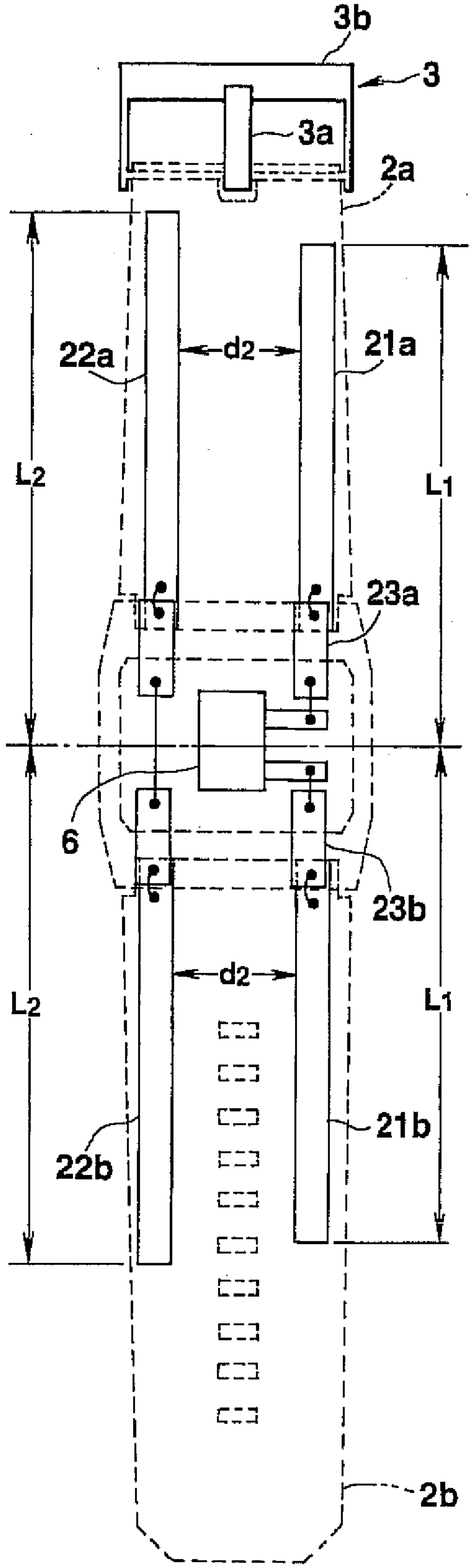
3b
3
3a
2a
22a
d_2
21a
L_2
L_1
23a
6
23b
d_2
L_2
L_1
22b
21b
2b

FIG.7B

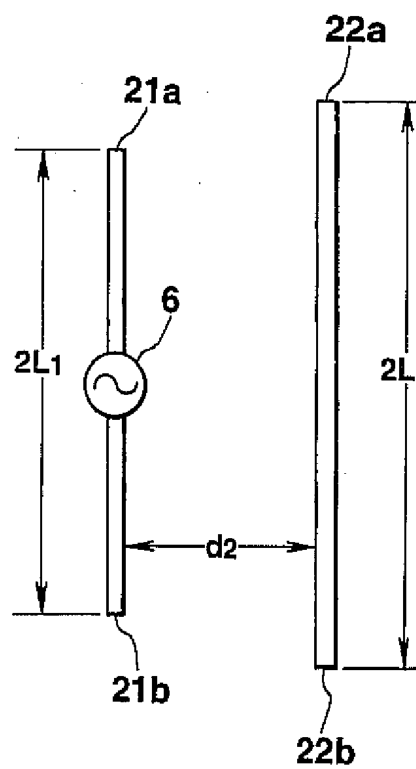
22a
21a
6
$2L_1$
$2L_2$
d_2
21b
22b

FIG.8A

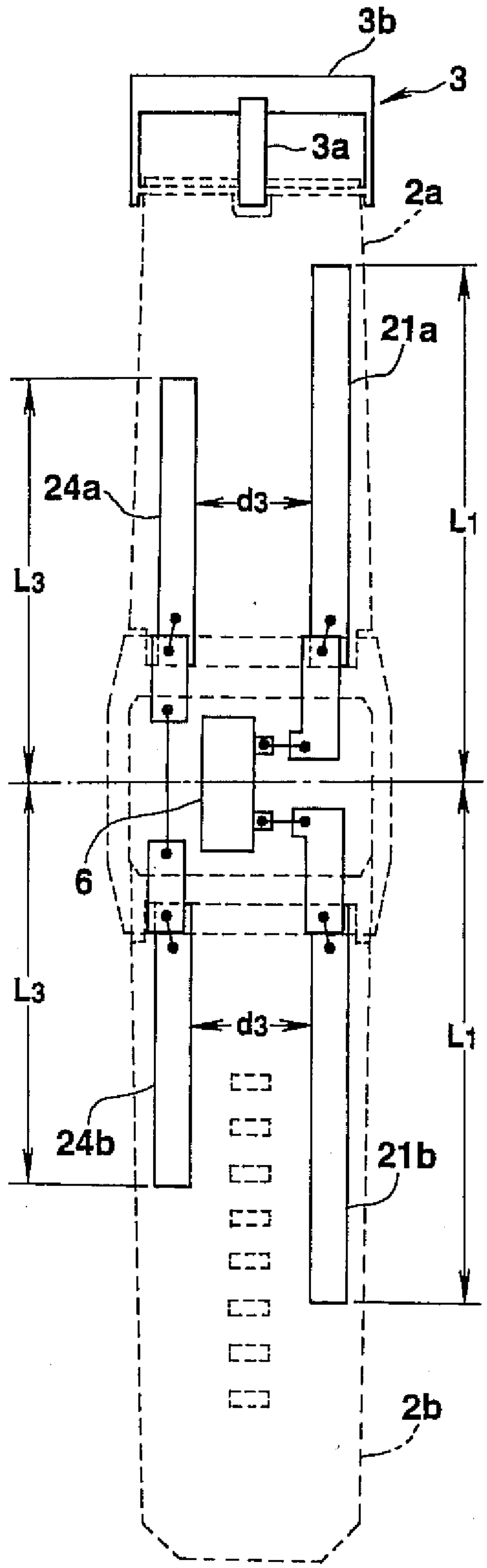
3b
3
3a
2a
21a
24a
d3
L1
L3
6
L3
d3
L1
24b
21b
2b

FIG.8B

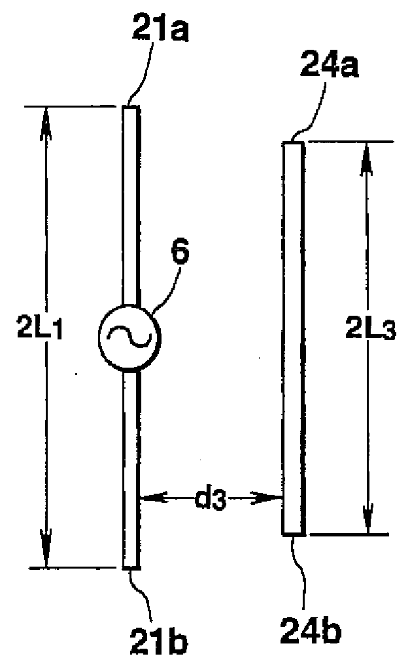
21a
24a
6
2L1
2L3
d3
21b
24b

FIG.9A

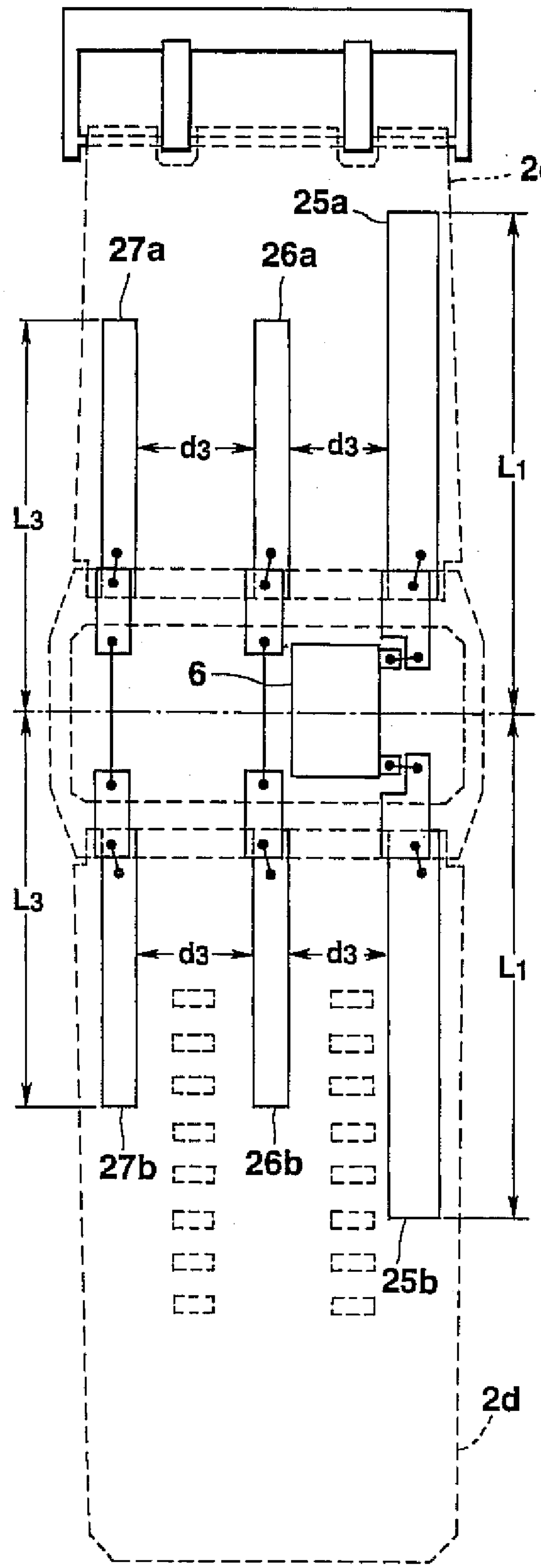
2c
25a
27a
26a
d3
d3
L1
L3
6
L3
d3
d3
L1
27b
26b
25b
2d

FIG.9B

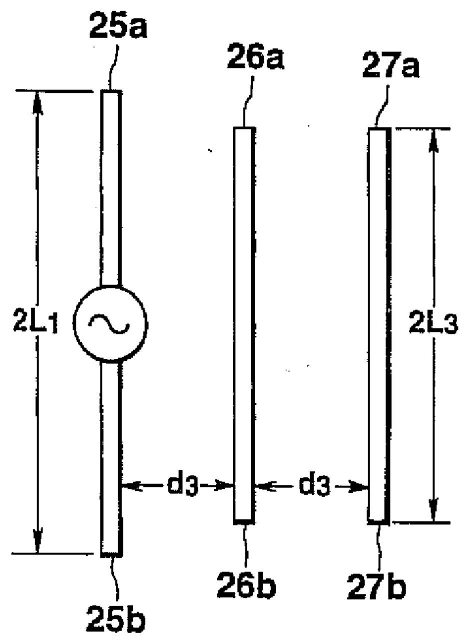
25a
26a
27a
2L1
2L3
d3
d3
26b
27b
25b

FIG.10A

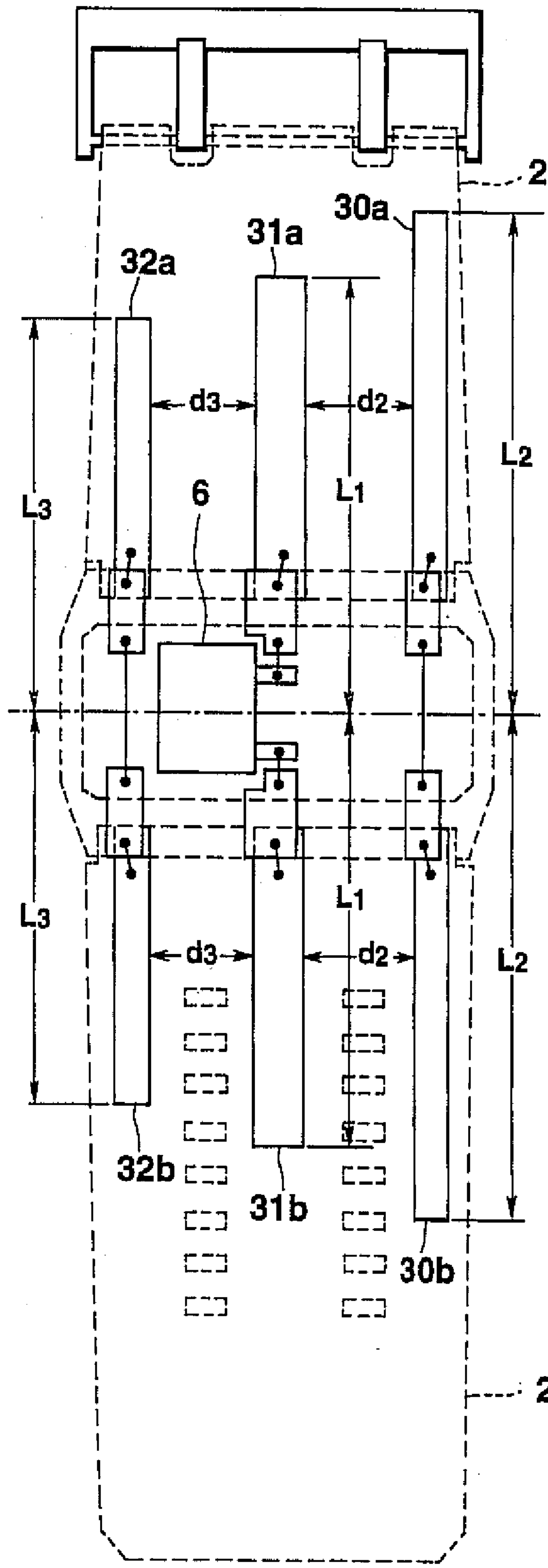

FIG.10B